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CORRECTION SHEET
EDU Research Report 1-63
"Decompression Sickness Among Divers: An Analysis of 935 Cases"

page 8, para. 3.13.2, line 5:

delete "bends" and insert "decompression sickness"

page 9, para. 3.14, table 12:

change heading "Decompression Sickness*" to "Decompression Schedule*"

page 9, para. 3.14, table 13:

change subheading "Percent of Divers Effected" to "Percent of Divers Affected"

page 11, para. 3.14.5.

delete lines 8 and 9. Add:

"a prolonged "saturation dive" (at rest for 12 hours or longer in recompression chamber). Following saturation dives, "bends" occurred five times more frequently in the lower than in the upper extremities. In the present series, there were 12 cases following "saturation dives", and the lower extremities were affected twice as often as the upper extremities."

page 24, para. 3.16.3, line 1:

change "twelve" to "thirteen"

page 24, para. 3.16.3, line 2:

change "eight" to "nine"

page 24, para. 3.16.3, line 5:

add after "three cases."--"; unknown treatment table, one case."

page 26, para. 3.16.11, line 5:

change "64" to "66" and change "17" to "16"

page 29, para. 3.19.1, line 8:

change "N=246" to "N=646"

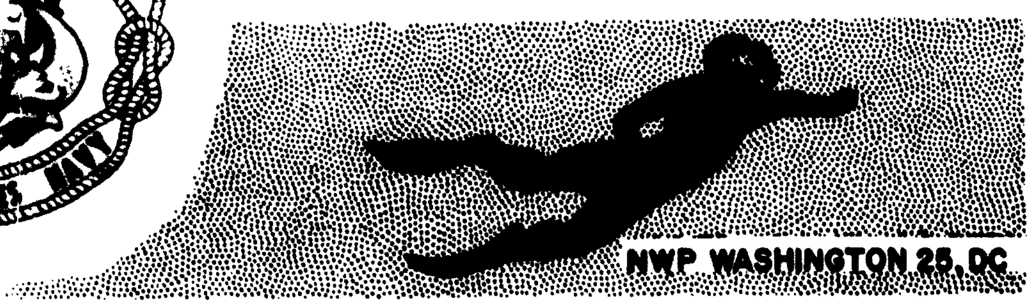
page 26, para. 3.16.11, line 3:

change "78" to "86"

Enclosure (1)

63-3-1

U. S. Navy
Experimental Diving Unit



U. S. NAVY EXPERIMENTAL DIVING UNIT
U. S. NAVAL STATION
(WASHINGTON NAVY YARD ANNEX)
WASHINGTON 25, D. C.

RESEARCH REPORT 1-63

DECOMPRESSION SICKNESS AMONG DIVERS: AN ANALYSIS OF 935 CASES

PROJECT F 015-06-02 TASK 3388, TEST 1

LT J. C. RIVERA, (MC) USN

1 February 1963

SUBMITTED:	APPROVED:	APPROVED:
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ABSTRACT

An analysis of 935 cases of decompression sickness among divers has been made from case reports on file at the U. S. Navy Experimental Diving Unit for the years 1946-1961. The effectiveness of the U. S. Navy Treatment Tables was determined. The report includes a comprehensive review of the clinical picture and the treatment of decompression sickness. The results of the initial use of the U. S. Navy Treatment Tables revealed that of 888 cases treated, 773 were completely relieved with one treatment table. There was a total of 115 failures (82 recurrences and 33 residuals). Of the 115 failures, 55 were due to acceptable or valid reasons complicating the treatment, and 60 were due to true failure of the treatment table. The total percentage true failure of the initial use of the treatment tables was 6.7%. The final results of the effectiveness of all treatment tables revealed that of 888 cases treated by one or more treatment tables there were 843 cases relieved and 45 residuals. Of the latter, only 15 were due to true failure of the treatment tables. The total percentage true failure after using one or more treatment tables was 1.7%. The above results are considered satisfactory. Forty-seven cases of the 935 were not treated with the U. S. Navy Treatment Tables. Their outcome is discussed in the report.

SUMMARY

Problem:

To analyze 935 cases of decompression sickness among divers, and to determine the effectiveness of the U. S. Navy Treatment Tables for decompression sickness.

Procedure:

All decompression sickness reports on file at the Experimental Diving Unit were analyzed and coded in the Diving Casualty Data Card. The reporting period included the years 1946-1961.

Findings:

(1) Two out of every ten divers treated by the U. S. Navy were civilians.

(2) Decompression sickness occurred following dives in which adequate decompression was used, or for which no decompression was specified in the U. S. Navy Decompression Tables.

(3) Tenders during treatment tables have occasionally developed decompression sickness.

(4) Decompression sickness is a disease of protean manifestations affecting several organ-systems. A comprehensive analysis of the clinical picture and treatment is included in the discussion section.

(5) The U. S. Navy Treatment Tables for decompression sickness are adequate.

(6) Chi square and correlational analyses of some of the data revealed the following:

(6.1) Prompt recompression treatment was usually associated with a better outcome ($X^2 = 19.0$ $p < .01$).

(6.2) In general, cases with a shorter time of onset of symptoms responded to treatment less satisfactorily than those with a longer time of onset ($X^2 = 8.76$ $p < .05$).

(6.3) Prompt recompression was related to the depth of relief ($C = .25$). Generally, the sooner recompression was started, the shallower the depth of relief.

(6.4) Cases with a shorter time before onset of symptoms generally obtained relief at at a more shallow depth. The relationship, however, was very weak ($C = .15$).

(6.5) A weak relationship ($C = .15$) between depth of dive and depth of relief was round. Usually, the shallower the depth of the dive, the shallower the depth of relief.

Recommendations:

(1) The reasons for tenders acquiring decompression sickness during or after a treatment table should be investigated.

(2) A diver should not leave an area where a recompression chamber is available until 24 hours after completion of the dive.

(3) All cases of decompression sickness should be given a recompression trial no matter what the elapsed time since the onset.

(4) An investigation of a modification in the shallower depths (less than 30 feet) of the U. S. Navy Treatment Tables 3 and 4 is recommended. The possibility of shortening the 6 hour stops at 60 feet, 50 feet, and 40 feet of Treatment Table 4 should be investigated.

ADMINISTRATIVE INFORMATION

The investigation was conducted as a part of Bureau of Ships, Navy Department Research Project F 015-06-02 Task 3388 Test 1.

Analysis of NavMed 816's, coding, and punching of the Diving Casualty Data Card commenced on 7 February 1962, and was completed on 30 May 1962. Sorting was started on 31 May 1962 and was completed on 29 June 1962. The final manuscript was completed on 15 January 1963.

This report is issued in the Experimental Diving Unit Research Report series, with unlimited distribution. Charges incurred in the execution of this project were lodged against allotment No. 13102/63.

ACKNOWLEDGMENTS

The author is indebted to the following students of the Medical Deep Sea Diving Technical Course, U. S. Naval School, Deep Sea Divers, who assisted in the preliminary coding of the Diving Casualty Data Card: M. G. GOODMAN, HM1, USN; R.O. COOMER, HM2, USN; J. C. CARROTHERS, Jr., HM2(SS), USN.

Mr. T. A. Banigan, Federal Systems Representative, Royal McBee Corporation, Washington, D. C. for his helpful guidance in the design of the Diving Casualty Data Card and his continued assistance with the necessary equipment for the sorting of the cards.

It is a privilege to acknowledge the author's great indebtedness for help and criticism to members of the staffs of the U. S. Navy Experimental Diving Unit and the U. S. Naval School, Deep Sea Divers. Special thanks are due to Lieutenant, junior grade D. A. WISE, MSC, USNR for the statistical analysis of the data and to Commander R. D. WORKMAN, MC, USN for reviewing the final manuscript for publication.

Finally, thanks to my wife, Mary, who patiently punched all the Diving Casualty Data Cards, assisted in the sorting and counting, and spent many hours typing the rough manuscript.

TABLE OF CONTENTS

LIST OF TABLES

1. INTRODUCTION

1.1 Background

1.1.1 A complete file of past diving casualty reports is maintained at the U. S. Navy Experimental Diving Unit, Washington 25, D. C. The earliest reports accumulated and still available began in 1933. These reports were submitted in compliance with a Bureau of Construction and Repair Letter Directive of 1933, later by the Bureau of Medicine and Surgery directives, and finally by the Manual of the Medical Department (1) and the U. S. Navy Diving Manual (2). In 1945 the original NavMed 816, "Report of Decompression Sickness and all Diving Accidents," from here on referred to as NavMed 816, was formulated and distributed. Its use was initiated in January 1946. In 1956 this form was revised.

1.1.2 There has never been a systematic handling of both past and current reports. A successful analysis of 113 cases of decompression sickness among divers was done by Duffner, et al. (3) in 1946. It was accomplished by means of coding the information from the original reports on marginally punched cards. In 1954, H. W. Gillen, then at the Naval Medical Research Laboratory, Groton, Connecticut initiated an effort toward analysis of NavMed 816's on file at the Experimental Diving Unit. This study used a marginally punched card (McBee Keysort); however, due to matters of greater military importance, the study was never completed (4). In 1957, a number of difficulties were encountered in attempting to set up Gillen's routine at the Experimental Diving Unit. The system was not pursued due to the shortcomings it had in view of the changed techniques in diving (5).

1.1.3 In 1959, Van Orden (5) wrote a thesis for qualification as a Submarine Medical Officer. In this thesis he discussed the problems of diving accident reporting and analysis. He proposed a system using a newly designed marginally punched card (McBee Keysort) with complete instructions to use the analysis system. It was after reading his excellent presentation that the author was stimulated to pursue this problem. The McBee Keysort data cards previously proposed by Gillen and Van Orden were revised and a new card, called the Diving Casualty Data Card (Appendix A), was designed. A new set of instructions was written for the system of accident report analysis (6).

1.1.4 The author selected decompression sickness as the first diving accident to be analyzed. An extensive review of the literature revealed that there were several large series of cases of decompression sickness among caisson workers, however, series of cases among divers were small. The largest series found was that by Brick (7). He reported that during 1900-08, not counting the slighter cases characterized by the men themselves as "rheumatics," he had upwards of 200 cases of diver's palsy. Sixty of the patients were dead before a doctor could be reached. Therefore, the present series comprises the largest series reported so far of cases of decompression sickness among divers. Furthermore, it comprises the most extensive analysis of the results in the use of U. S. Navy Treatment Tables* for decompression sickness.

1.2 Objective

The purpose of this report is to make a comprehensive analysis of 935 cases of decompression sickness among divers and to determine the effective-

* Hereafter referred to as Treatment Tables

ness of the Treatment Table.

2. PROCEDURE

Using the instructions and definitions written by the author (6), NavMed 816's on file at the Experimental Diving Unit in which the diagnosis of decompression sickness was established were analyzed and coded on the Diving Casualty Data Card. The reporting period included the years 1946-1961, from which a total of 935 cases were coded. Results obtained after the cards were coded and sorted are shown in the following sections.

3. RESULTS AND DISCUSSION

3.1 General Considerations

In the analysis of the data only information supplied can be relied upon. It can never be assumed that factors not mentioned were not necessarily present in any particular case. It must be emphasized that the present reporting system made the determination of incidence impossible since the total number of dives was not available. Because of the numerous findings, each section of results was incorporated with its respective discussion.

3.2 Classification of Divers - (Table 1)

The data reveal that 77.2% of the cases were U. S. Navy personnel and 21.5% were civilian personnel. This shows that 2 out of every 10 divers treated by the U. S. Navy were civilians.

TABLE 1
CLASSIFICATION OF DIVERS

CLASSIFICATION	NUMBER OF CASES	PERCENT OF TOTAL
U. S. Navy	722	77.2
Civilian - Commercial	149	15.9
Civilian - Sport	31	3.3
Civilian - Foreign National	21	2.3
Other U. S. Military	9	1.0
Foreign National Navy	3	0.3
TOTAL	935	100.0

3.3 Age Groups of Divers - (Table 2)

Several authors (8) (9) (10) have stated that the incidence of decompression sickness increases with age, especially in men over 40 years of age. Inspection of the data shows that most of the cases were within the ages of 26-30 years. There is a noticeable decrease after 31 years. These findings can be explained on the basis that the U. S. Navy does not train divers after 30 years and does not permit any diving after age 40 except under special situations as stated in the Manual of the Medical Department (1). Since 77.2% of the divers in this series are U. S. Navy divers, it is obvious that they will account for the high percentage of cases between ages 21-30 and for the noticeable decrease after age 31.

TABLE 2
AGE GROUPS OF DIVERS

AGE IN YEARS*		NUMBER OF CASES	PERCENT OF TOTAL
Under 20		26	2.8
21-25		210	22.5
26-30		307	32.8
31-35		214	22.9
36-40		118	12.6
Over 40		36	3.8
Unknown		24	2.6
	TOTAL	935	100.0

* Mean age = 28.4 years

3.4 Body Build - (Table 3)

The classification used was based on the observations of the persons who completed the NavMed 816's. Only 460 reports contained this information. It is unknown to the author whether weight and height tables were considered in this classification. Several authors (9) (11) (12) have stated that the incidence of decompression sickness is higher in subjects who are over standard weight. In the present series the greatest number of cases (43.7%) occurred in divers of a medium size body build. Again, this was probably due to the fact that most of the divers in this series were U. S. Navy divers and they will fit this description since the Manual of the Medical Department (1) states that there will be no more than 10% variation of weight from standard weight and height tables. At the present time there is a pilot study being conducted at the Experimental Diving Unit in vital statistics among U. S. Navy divers who have not had decompression sickness. On preliminary evaluation it appears that the distribution in the control group will be similar to the one in this series.

TABLE 3
BODY BUILD OF DIVERS (Years 1956-61, inclusive)

BUILD	NUMBER OF CASES	PERCENT OF TOTAL
Slender	61	13.3
Medium	201	43.7
Heavy	105	22.8
Obese	75	16.3
Unknown	18	3.9
TOTAL	460	100.0

3.5 <u>Divers Qualifications - (Table 4)</u>

Only military personnel with valid qualifications were included (701 cases). All civilian and foreign divers plus a few non-qualified military personnel made a total of 234 cases. The data show that 88% of the qualified divers were deep sea or salvage divers.

TABLE 4
DIVERS QUALIFICATIONS

QUALIFICATIONS	NUMBER OF CASES	PERCENT OF TOTAL
Deep Sea or Salvage	616	87.9
Student Diver	51	7.3
Underwater Demolition Team	19	2.7
Explosive Ordnance Disposal Team	14	2.0
Underwater Swimmer - (Scuba)	1	0.1
TOTAL	701	100.0

3.6 <u>Purpose of the Dive - (Table 5)</u>

The two most frequent purposes of the dives were work and experimentation. It is important to note that in 16 cases the purpose of the dive was as a tender in a treatment table. There is no explanation for this phenomenon in which the treatment cures the patient but the tender acquires the disease.

3.7 <u>Type of Dive - (Table 6)</u>

Most of the dives were in open water. More cases occurred during wet-chamber dives than during dry-chamber dives. This is probably due to the fact that more dives are made in wet-chambers than in dry-chambers. An unpublished study at the Experimental Diving Unit showed that "bends" were more frequent in dry dives than in wet dives. This study was done with a 300 feet dive for 10 minutes bottom time (13).

TABLE 5
PURPOSE OF THE DIVE

PURPOSE	NUMBER OF CASES	PERCENT OF TOTAL
Work	520	55.6
Experimentation	228	24.4
Training of diver	74	7.9
Recreation	48	5.1
Requalification	35	3.7
Tender on treatment table	16	1.7
Selection of personnel	10	1.1
Others	4	0.5
TOTAL	935	100.0

TABLE 6
TYPE OF DIVE

TYPE	NUMBER OF CASES	PERCENT OF TOTAL
Open Water	581	62.1
Chamber-wet	181	19.4
Chamber-dry	162	17.3
Submarine Escape Training Tank	11	1.2
TOTAL	935	100.0

3.8 <u>Type of Work - (Table 7)</u>

Most of the cases occurred in dives in which work was moderate or heavy. Heavy work or exercise will increase susceptibility to decompression sickness (14).

TABLE 7
TYPE OF WORK DURING THE DIVE

TYPE OF WORK	NUMBER OF CASES	PERCENT OF TOTAL
Moderate	326	34.9
Heavy	272	29.1
None	181	19.4
Mild	136	14.5
Unknown	20	2.1
TOTAL	935	100.0

3.9 Type of Equipment - (Table 8)

There were more cases while using the deep sea rig than any other equipment. This finding was expected since most of the diving during the past 16 years has employed the deep sea rig. A study done by the author (15) of the cases during years 1960-1961 inclusive, revealed that there were more cases of decompression sickness among SCUBA divers than deep sea divers. This was probably due to the increased popularity of SCUBA diving during the past 4-5 years.

TABLE 8
TYPE OF EQUIPMENT USED DURING THE DIVE

TYPE OF EQUIPMENT	NUMBER OF CASES	PERCENT OF TOTAL
Deep Sea - Air	436	46.6
Recompression chamber	167	17.9
Scuba - open	134	14.3
Lightweight - surface supply	111	11.9
Deep Sea - HeO_2	51	5.5
No equipment	9	1.0
Momsen Lung	7	0.7
Scuba - semi-closed	6	0.6
Experimental equipment	4	0.4
Submarine rescue bell	1	0.1
Unknown	9	1.0
TOTAL	935	100.0

3.10 Breathing Media - (Table 9)

Air was the most frequent breathing media used. Helium-oxygen mixtures and nitrogen-oxygen mixtures were used only by U. S. Navy divers.

TABLE 9
BREATHING MEDIA USED DURING THE DIVE

BREATHING MEDIA USED	NUMBER OF CASES	PERCENT OF TOTAL
Air	838	89.6
HeO_2	85	9.1
Other mixture - N_2O_2	12	1.3
TOTAL	935	100.0

3.11 Depth of Dive - (Table 10)

In cases of repetitive dives, the maximum depth attained during the dives was used as the depth of dive. Most authorities agree that it is impossible to develop decompression sickness in dives to depths less than 33 feet. It has been shown that a diver may remain for 24 hours at 33 feet and surface without decompression sickness (14). However, in the present series there were 3 cases of decompression sickness which occurred after dives to depths less than 33 feet. Two of these cases were previously reported by Welham and Waite (16). The majority of cases (46.0%) in the present series occurred after dives to depths between 100-165 feet. This is the depth range where most diving is done. Cases following repetitive dives were more frequent at depths less than 165 feet.

TABLE 10
DEPTH OF THE DIVE

DEPTH GAUGE IN FEET	NUMBER OF CASES	PERCENT OF TOTAL	NUMBER OF CASES REPETITIVE DIVES
0 - 33	3	0.3	0
34 - 99	208	22.2	74
100 - 165	430	46.0	76
166 - 231	160	17.1	24
232 - 297	60	6.4	4
298 - 495	68	7.3	0
Unknown	6	0.7	2
TOTAL	935	100.0	180

3.12 Bottom Time - (Table 11)

In cases of repetitive dives, the sum of the bottom time of the dives was used for a final bottom time. Most of the cases occurred after dives in which the bottom time was less than 45 minutes (59.2%), or greater than 120 minutes (17.2%). However, 72 out of 161 cases that occurred after bottom times greater than 120 minutes were repetitive dives. It is difficult to correlate bottom time with the occurrence of bends unless it is done in conjunction with the depth of the dive and vice versa.

3.13 Decompression Schedule - (Table 12)

3.13.1 It is unknown to the author how many times these decompression schedules were used successfully; therefore, the incidence of decompression sickness cannot be determined. The greatest number of cases was due to using less than the proper schedule during decompression in accordance with U. S. Navy Decompression Tables. Most of these cases were civilians. Sixty-four cases occurred in instances where no decompression was indicated in the U. S. Navy Decompression Tables. In general, the incidence of

TABLE 11
BOTTOM TIME OF THE DIVE

BOTTOM TIME - MINUTES	NUMBER OF CASES	PERCENTAGE	NUMBER OF CASES REPETITIVE DIVES
Less than 15	197	21.2	6
16 - 30	208	22.2	24
31 - 45	149	15.9	16
46 - 60	60	6.4	10
61 - 90	84	9.0	33
91 - 120	45	4.8	16
Greater than 120	161	17.2	72
Treatment tables - tenders	16	1.7	0
Unknown	15	1.6	9
TOTAL	935	100.0	186

decompression sickness following an adequate decompression schedule or a no-decompression dive can most easily be explained on the basis that the U. S. Navy Decompression Tables are not entirely safe. A small incidence of decompression sickness is expected due to the many variables present during the dive. Examples of these variables are: physical condition of the diver, type of work, type of equipment, sea state, breathing media, and others.

3.13.2 An interesting finding was that eleven tenders acquired decompression sickness after Treatment Table 4, three after Treatment Table 2, and two after Treatment Table 3 (air). Although it is unknown how many tenders were present during the 57 times that Treatment Table 4 was used, eleven is definitely a high number of bends cases. This phenomenon following Treatment Table 4 deserves further study.

3.14 Signs and Symptoms of Decompression Sickness

3.14.1 First, for the purpose of this paper, decompression sickness has been defined in terms of signs and symptoms. Shilling (17) (18) classified the symptomatology of decompression sickness as it is related to the various body systems, namely: (a) the cerebrospinal system, (b) the cardio-vascular system, (c) the pulmonary system, (d) the urogenital system, (e) the structural system (including osseous, connective, muscular, and fatty tissues), and (f) the dermal system. Because of the possible multiplicity of symptoms in any one case, it will not be expected that only one feature of the clinical picture will necessarily be manifested.

3.14.2 The classification used in this report is a modification of that used by Shilling. The signs and symptoms in Table 14 were classified into the following organ systems (Table 13): (1) central nervous system, (2) peripheral nervous system, (3) "bends" (localized skeleto-muscular pain), (4) skin, and (5) respiratory system.

TABLE 12
DECOMPRESSION SCHEDULE USED DURING THE DIVE

DECOMPRESSION SICKNESS*	NUMBER OF CASES	PERCENTAGE
Less than proper	268	28.7
Standard Air Table (1952)	220	23.5
Experimental	201	21.5
No decompression required	64	6.9
Exceptional Exposure Table (1959)	53	5.7
Surface decompression - air (1952)	33	3.5
Standard Air Table (1959)	32	3.4
Helium-Oxygen Tables (1959)	24	2.6
HeO_2, Surface Decompression O_2 (1959)	15	1.6
Treatment Table 4 (tender)	11	1.2
Surface Decompression - O_2 (1952)	6	0.6
Surface Decompression - Air (1959)	3	0.3
Treatment Table 2 (tender)	3	0.3
Treatment Table 3 Air (tender)	2	0.2
TOTAL	935	100.0

* According to U. S. Navy Decompression Tables, U. S. Navy Diving Manual. Dates refer to publication year of the manuals.

TABLE 13
PERCENTAGE INCIDENCE OF ORGAN-SYSTEM INVOLVED DURING ILLNESS

ORGAN SYSTEM	PERCENT OF DIVERS EFFECTED			PERCENT OF TUNNEL WORKERS EFFECTED		
	Rivera	Behnke (9)	Duffner (3)	Thorne (24)	Levy (23)	Keays (21)
"Bends" (Localized Skeleto-muscular Pain)	91.8	72.2	85.8	55.0	91.7	90.3
Central Nervous System	25.8	10.2	34.4	27.5	8.1	7.9
Peripheral Nervous System	21.6	-	-	-	-	-
Skin	14.9	13.6	0.9	10.0	-	-
Respiratory	2.0	4.0	7.9	7.5	0.1	1.6
TOTAL NUMBER OF CASES	935	159	113	200	680	3692

(1) Central Nervous System: This refers to involvement of the brain and spinal cord. In these cases the clinical picture is usually complicated. Most cases are referable to pathological processes in the spinal cord. Some of the more frequent manifestations are motor and sensory disturbances manifested as paraplegia, monoplegia, paresis, paralysis, spasticity, loss of bladder and rectal control, muscular weakness, altered reflexes, and paresthesias, frequently described as numbness or "pins and needles" sensation. When cerebral symptoms are encountered they may manifest as convulsive seizures, unconsciousness, stupor, collapse, nausea, vomiting, visual disturbances, dizziness, vertigo, headache, nystagmus, incoherence of speech, aphasia, restlessness, agitation, confusion, and personality changes. In cases of dizziness or vertigo, sometimes called the "staggers," regardless of whether the symptoms are due to labyrinthic or central nervous system origin, they are all classified under the latter system.

(2) Peripheral Nervous System: This includes involvement of the cranial nerves, spinal verves, and the visceral or autonomic nervous system. There may be motor and sensory disturbances manifested as numbness, paresthesia, muscular weakness, muscular twitching, paralysis, or paresis. Sometimes it is difficult to determine if the lesion is peripheral or central in origin. Many cases with severe decompression sickness will have involvement of both central or peripheral nervous systems. In the cases of cranial nerve and autonomic nervous system involvement, it is difficult to determine from the information given in the accident reports exactly what system is involved. An attempt has been made to classify these symptoms as accurately as possible.

(3) "Bends" (Localized Skeleto-muscular Pain): This includes painful involvement of the structural system, including osseous, connective, muscular, or fatty tissues.

(4) Skin: Pruritus or itching is one of the most common symptoms and frequently it is the first and only symptom to appear. It was not included in Table 14 because it is a very mild manifestation of decompression sickness which by itself does not require treatment. The skin manifestations in this category include rash, lividity, marbling, mottling, blotching, and erythema. Areas of swelling and subcutaneous emphysema occur in occasional cases.

(5) Respiratory System: This includes attacks of dyspnea and a feeling of oppression in the chest known as "chokes."

3.14.3 The percentage incidence of each organ-system affected were as follows: "bends," 91.8%; central nervous system, 25.8%; peripheral nervous system, 21.6%; skin, 14.9%; and respiratory system, 2.0% of the cases. "Bends" was not present as a symptom in 8.2% of the cases. The above findings were compared with cases in tunnel workers (Table 13). In the present series and in Duffner's series (3), percentages were calculated for each organ system affected, but in some cases more than one organ system was effected. The percentages shown, except those in the present series, were obtained by classifying the symptoms given by the authors into the modified classification used in this report. The other authors did not differentiate peripheral nervous systems lesions from central nervous system lesions. Cases of vertigo or "staggers" were classified into the central nervous system group. Comparing the findings on tunnel workers with those on divers, it can be concluded that decompression sickness in divers was of a more serious nature than in tunnel workers. "Bends" was also the most common manifestation of decompression sickness in divers. There was more involvement of the nervous system in divers with decompression sickness than in tunnel workers.

3.14.4 Frequency of Signs and Symptoms - (Table 14)

(1) The 12 most frequent signs or symptoms were as follows: localized pain (91.8%), numbness or paresthesia (21.2%), muscular weakness (20.6%), skin rash (14.9%), dizziness or vertigo (8.5%), nausea or vomiting (7.9%), visual disturbances (6.8%), paralysis (6.1%), headache (3.9%), unconsciousness (2.7%), urinary disturbances (2.5%), dyspnea ("chokes") (2.0%). The signs and symptoms were also classified into the frequency of appearance as the first manifestation. In 79.6% of the cases, "bends" appeared as the first symptom. Other initial signs or symptoms during the illness were, in order of frequency: skin rash, 4.4%; numbness of paresthesis, 4.3%; dizziness or vertigo, 2.5%; visual disturbances, 1.4%; muscular weakness, 0.8%; nausea or vomiting, 0.8%; unconsciousness, 0.6%; headaches, 0.5%; "chokes," 0.4%; paralysis, 0.2%; and fatigue, 0.2%.

3.14.5 Location of Pain ("bends") - (Table 15)

(1) In the present series it was found that the upper extremities were affected in 53.8% of the cases. The shoulder and elbow were the most frequent sites of pain, in a ratio of 2 to 1. The lower extremities were affected in 27.1% of the cases. The knee and hip were the most frequent sites of pain in a ratio of 3 to 1. Behnke (9) and Duffner (3) found similar results among two series of decompression sickness in divers. Among the 113 cases reported by Duffner, 17 had symptoms following a prolonged "saturation dives," and the lower extremities were affected twice as often as the upper extremities.

(2) The location of pain has been analyzed by several authors (Table 15). An interesting finding was that in tunnel workers the lower extremities were affected more frequently than the upper extremities. Bornstein (11) explained this finding by stating that due to poor circulation of the lower extremities, the elimination of nitrogen during decompression will be retarded. Behnke (9) gives a similar explanation and also stated that the exercised part of the body may be more susceptible to "bends." Van Der Aue (14) showed that exercise will increase the incidence of "bends." Harvey (19) showed that muscular exercise starts the formation of gas nuclei, which on decompression may grow to considerable size producing "bends." Knisely (20), while studying "bends" in low pressure chambers, showed that a decreased rate of blood flow through an extremity either initiated the pain, or, if the pain were already present, it made it worse. The decreased blood flow was obtained by having the subjects hold the arms or legs in the vertical position while at altitude. It was interesting that in the subject who were given aminophyllin, which presumably dilates small vessels, elevation of the arm or leg usually did not bring on the pain.

TABLE 14
FREQUENCY OF SIGNS AND SYMPTOMS PRESENT IN 935 CASES OF DECOMPRESSION SICKNESS

SIGN OR SYMPTOM	NUMBER OF INSTANCES WITHIN 935 CASES	PERCENTAGE OF INSTANCES WITHIN 935 CASES	NUMBER OF INSTANCES WITHIN 935 WHERE MANIFESTED INITIALLY	PERCENTAGE OF INSTANCES WITHIN 935 CASES
Localized Pain	858	91.8	744	79.6
Numbness or Paresthesia	199	21.2	41	4.3
Muscular Weakness	193	20.6	8	0.8
Skin Rash	140	14.9	42	4.4
Dizziness or Vertigo	80	8.5	24	2.5
Nausea or Vomiting	74	7.9	8	0.8
Visual Disturbances	64	6.8	14	1.4
Paralysis	57	6.1	2	0.2
Headache	37	3.9	5	0.5
Unconsciousness	26	2.7	6	0.6
Urinary Disturbances	24	2.5	0	-
Dyspnea ("chokes")	19	2.0	4	0.4
Personality Changes	15	1.6	0	-
Agitation or Restlessness	13	1.3	0	-
Fatigue	12	1.2	2	0.2
Muscular Twitching	12	1.2	0	-
Convulsions	11	1.1	0	-
Incoordination	9	0.9	0	-
Equilibrium Disturbances	7	0.7	0	-
Localized Edema	5	0.5	0	-
Intestinal Disturbance	4	0.4	0	-
Auditory Disturbance	3	0.3	0	-
Cranial Nerve Involvement	2	0.2	0	-
Aphasia	2	0.2	0	-
Hemoptysis	2	0.2	0	-
Emphysema-subcutaneous	1	0.1	0	-

(3) If we assume that divers perform most of their work with the upper extremities, and that tunnel workers perform as much work with the lower extremities as with the upper extremities, and that tunnel workers spend longer hours working in a standing position, one might be able to explain the discrepancy in the most frequent site of localized pain on poor circulation of the lower extremities. If the hypothesis of poor circulation of the lower extremities is true, it may be that the tight deep sea diving dress around the lower extremities acts as an elastic support of the legs and improves circulation, thus diminishing the incidence of "bends" in the lower extremities in divers.

(4) To determine if this hypothesis were tenable, cases were grouped on the basis of equipment used during the dive and the location of "bends" was tabulated. There was no significant difference in the distribution of pain among wet dives when the diver was using deep sea gear, SCUBA gear, shallow water gear or no equipment. It was found in these groups that the upper extremities were affected 2.3 times more frequently than the lower extremities.

TABLE 15
PERCENTAGE DISTRIBUTION OF PAIN ("BENDS")

LOCATION	PERCENT OF DIVERS AFFECTED			PERCENT OF TUNNEL WORKERS AFFECTED				
	Rivera	Behnke (9)	Duffner (3)	Eardman (22)	Keays (21)	Levy (23)	Bornstein (11)	Campbell (36)
Upper Extremity(ies)	53.3	69.5	66.4	38.0	20.6	17.6	16.8	7.0
Lower Extremity(ies)	27.1	25.2	26.2	74.0	61.9	79.0	60.0	85.0
Both upper & lower extremities	-	5.3	5.6	-	16.6	3.5	22.8	8.0
Back	6.4	-	-	1.0	-	-	-	-
Head and Neck	4.7	-	-	1.0	-	-	-	-
Chest	4.3	-	-	2.0	-	-	-	-
Abdomen	3.4	-	1.9	5.0	-	-	-	-
TOTAL NUMBER OF CASES WITH PAIN	858	131	107	1419	3030	461	615	650

However, in the cases of dry dives in pressure chambers, the frequency of "bends" in the upper and lower extremities were the same. Therefore, it appears that the important factor determining whether "bends" will occur more frequently in the upper or lower extremities is whether a dive is wet or dry. Apparently, the small difference in pressure between the upper and lower extremities while the diver stands in the water improves vascular tone and circulation of the lower extremities and is enough to influence the location of "bends."

(5) The exercise of work performed by the extremity is probably not the determining factor since in saturation dives while at rest, the lower extremities were affected more frequently than the upper extremities. Behnke (9) stated that apparently the duration of the compression period influences the location of "bends."

(6) The above discussion has been speculation by the author. A true explanation is not evident from the literature nor the available data.

3.14.6 Onset of Signs or Symptoms in Decompression Sickness - (Table 16)

(1) The onset of signs or symptoms after the completion of a dive varies widely in decompression sickness. However, the greatest number of cases had a relatively rapid onset. The data showed 9.1% of the cases developed signs or symptoms during the decompression period or ascent. At the end of the first hour, 54.7% of the cases had already shown manifestations of the illness; by the end of the second hour, 66.8%; the end of the sixth hour, 86.2%; and by the end of the twelveth hour, 92.8%. A delay of as long as 13-24 hours was seen in 2.3% of the cases, and 0.3% developed 24 hours after completion of the dive. No cases developed after a delay of 36 hours.

(2) In Duffner's (3) series among divers, 43.9% of the cases manifested symptoms within the first two hours and 71.3% within the first six hours; however, 3.9% had a delay of as long as 13-24 hours before the appearance of symptoms. Keays (21) reported that among 3692 cases of decompression sickness in tunnel workers, about 50% occurred within 30 minutes, 85% within 1 hour, 95% within 3 hours, and 1% delayed over 6 hours. Eardman (22) reported that in 1419 cases of tunnel workers with decompression sickness, 43% of the cases occurred within 30 minutes and 75% within an hour after decompression. Levy (23) reported 436 cases of decompression sickness in tunnel workers among which 65.2% of the cases developed within the first hour and 81.9% within the second hour. Among 300 cases in tunnel workers, Thorne (24) reported that 60% manifested symptoms within the first hour and 95% within the second hour.

(3) Summarizing all series, 97-98% of all cases usually occurred within 12 hours after completion of decompression. In tunnel workers, the disease manifests itself sooner than in divers. It is rare to see cases in tunnel workers appearing 12 hours after decompression or in divers, after 24 hours.

(4) The above results show the importance of retaining compressed air workers and divers near a recompression chamber after completion of decompression until the greatest danger of appearance of symptoms has passed. It appears that 24 hours is the safest period to wait before a diver leaves an area where a recompression chamber is available.

TABLE 16
INCIDENCE OF TIME OF ONSET OF SIGNS AND SYMPTOMS IN DECOMPRESSION SICKNESS

TIME OF ONSET	NUMBER OF CASES	PERCENT OF TOTAL
During decompression	85	9.1
First hour	426	45.6
1 - 2 hours	113	12.1
3 - 6 hours	182	19.5
7 - 12 hours	62	6.6
13 - 24 hours	22	2.3
25 - 36 hours	3	0.3
Unknown	42	4.5
TOTAL	935	100.0

3.15 Treatment of Decompression Sickness

3.15.1 Background

(1) Recompression has long been accepted as the only effective method of treating decompression sickness. Pol and Watelle (25) in 1854 recognized clearly the nature of the disease in caisson workers, and established the specific treatment of the disease. By returning patients to compressed air they afforded relief of symptoms. In 1897 Zuntz (26) suggested the use of oxygen in conjunction with recompression to hasten elimination of the nitrogen, but, because of the known toxicity of oxygen at high concentrations, its use was not widely accepted. However, Von Schrotter (27), in 1906, again suggested the use of oxygen to hasten nitrogen elimination. In 1907, Boinet (28) recommended its use in the treatment of "divers disease." In 1925, Sayers et al. (29) suggested the use of helium-oxygen mixtures in the treatment of decompression sickness.

(2) In 1937, Behnke and Shaw (30) elucidated some of the basic principles underlying recompression as a therapeutic procedure and outlined a method of utilizing oxygen. With a combination of recompression and the use of oxygen, Yarbrough and Behnke (31) reported the successful treatment of 49 out of 50 divers with decompression sickness which occurred after exposure in high pressure helium-oxygen atmospheres. However, through the years, opinion as to the amount of pressure to be used and the time to be spent at various levels in the subsequent decompression has been quite diverse. In general, there are four methods of treatment which are as follows: (a) use of pressure of the original dive, (b) use of pressure greater than the original dive, (c) use of barely sufficient pressure to relieve symptoms, (d) use of pressure greater than required for relief of symptoms. The Treatment Tables are based on the last method. Clinical and experimental observations have shown that this is the best approach (3) (30) (31) (32) (33).

(3) In order to provide U. S. Navy personnel in the field with a simplified method of treatment for decompression sickness when the services of a medical officer might not be available, a procedure was formulated and published in the Bureau of Medicine and Surgery Newsletter, May 1944 (34). Reports from the field, and experience at the Experimental Diving Unit showed that the use of these treatment tables proved to be inadequate for the treatment of decompression sickness following dives during which compressed air was breathed. The recurrence rate was as high as 50%. The inadequacy of these treatment procedures were verified by the experimental results of Van Der Aue, et al (32). One of the treatment tables referred to as the "long oxygen table" was the one used successfully by Yarbrough and Behnke (31) in treating 49 out of 50 cases of decompression sickness, but these cases followed a dive in which helium-oxygen was the breathing medium.

(4) In order to formulate adequate and comprehensive tables for the treatment of decompression sickness and air embolism, a series of tests were performed in 1945 at the Naval Medical Research Institute and the Experimental Diving Unit. The following features were incorporated into the final treatment procedures after tests of ten individual treatment tables (32). The features were developed from principles formulated by Behnke and Shaw (30), Behnke (33), and Yarbrough and Behnke (31), and are as follows: (a) the limitation of maximal pressure applied during recompression to 75 pounds per square inch gauge* (165 feet sea water equivalent) and the maintenance of this pressure for periods of at least 30 minutes or for as long as two hours, (b) prolonged recompression for periods of 12-34 hours, or longer, at pressure levels equivalent to depths between 30-60 feet, and (c) the inhalation of oxygen at pressure levels equivalent to 60 feet or less.

(5) Consequently, the Treatment Tables (Table 17) (32) were formulated and promulgated to the Naval Service in 1945. There are 4 treatment tables, 2 for cases with symptoms of pain only, dependent upon the depth of relief, and 2 tables for serious cases, dependent upon the time such symptoms are relieved. The breathing media may include air or oxygen depending on the treatment table used. A mixture of helium (80%) and oxygen (20%) may be substituted for air at any time during their use except to replace oxygen breathing.

(6) In conjunction with the treatment of 113 cases of decompression sickness among Navy divers, the rationale of the above principles and their incorporation into treatment tables were analyzed and discussed in 1946 by Duffner, et al (3).

(7) Of the 113 divers treated with the new treatment tables, four suffered a recurrence of symptoms and required subsequent recompression. Of the four recurrences, three occurred following the employment of Treatment Table 1 and can be attributed to insufficient recompression. These patients' symptoms were relieved at 70 and 78 feet respectively, yet they were only recompressed to 100 feet instead of 165 feet, as recommended. The other treatment failure following the employment of Treatment Table 1

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* Referred to as psi

TABLE 17

Treatment of Decompression Sickness and Air Embolism. (2) (32)

Stops		Bends—Pain only				Serious Symptoms	
Rate of descent—25 ft. per min. Rate of ascent—1 minute between stops.		Pain relieved at depths less than 66 ft. Use table 1—A if O_2 is not available.		Pain relieved at depths greater than 66 ft. Use table 2—A if O_2 is not available. If pain does not improve within 30 min. at 165 ft. the case is probably not bends. Decompress on table 2 or 2—A.		Serious symptoms include any one of the following: 1. Unconsciousness. 2. Convulsions. 3. Weakness or inability to use arms or legs. 4. Air embolism. 5. Any visual disturbances. 6. Dizziness. 7. Loss of speech or hearing. 8. Severe shortness of breath or chokes. 9. Bends occurring while still under pressure.	
						Symptoms relieved within 30 minutes at 165 ft. Use table 3	Symptoms not relieved within 30 minutes at 165 ft. Use table 4
Pounds	Feet	Table 1	Table 1-A	Table 2	Table 2-A	Table 3	Table 4
73.4	165			30 (air)	30 (air)	30 (air)	30 to 120 (air)
62.3	140			12 (air)	12 (air)	12 (air)	30 (air)
53.4	120			12 (air)	12 (air)	12 (air)	30 (air)
44.5	100	30 (air)	30 (air)	12 (air)	12 (air)	12 (air)	30 (air)
35.6	80	12 (air)	12 (air)	12 (air)	12 (air)	12 (air)	30 (air)
26.7	60	30 (O_2)	30 (air)	30 (O_2)	30 (air)	30 (O_2) or (air)	6 hrs. (air)
22.3	50	30 (O_2)	30 (air)	30 (O_2)	30 (air)	30 (O_2) or (air)	6 hrs. (air)
17.8	40	30 (O_2)	30 (air)	30 (O_2)	30 (air)	30 (O_2) or (air)	6 hrs. (air)
13.4	30		60 (air)	60 (O_2)	2 hrs. (air)	12 hrs. (air)	First 11 hrs. (air) Then 1 hr. (O_2) or (air)
8.9	20	5 (O_2)	60 (air)		2 hrs. (air)	2 hrs. (air)	First 1 hr. (air) Then 1 hr. (O_2) or (air)
4.5	10		2 hrs. (air)	5 (O_2)	4 hrs. (air)	2 hrs. (air)	First 1 hr. (air) Then 1 hr. (O_2) or (air)
Surface			1 min. (air)		1 min. (air)	1 min. (air)	1 min. (O_2)

Time at all stops in minutes unless otherwise indicated.

cannot be explained. The recurrence following the procedure in Treatment Table 2 can be attributed to a faulty oxygen breathing apparatus which permitted a significant dilution of the oxygen with air. The residual following Treatment Table 4 was of a temporary nature and was followed by complete recovery. The residual was in a diver who reported paresthesia and weakness in his hand 21½ hours after onset. He had a residual anesthesia of the palm. The residual following Treatment Table 2-A was not explained, but apparently it was temporary since it was considered as a complete recovery.

(8) In summary, there was only one true recurrence of Treatment Table 1, and two temporary residuals following Treatment Table 2-A and Treatment Table 4, respectively. All cases eventually recovered completely.

(9) Although the number of patients treated with the new treatment tables were too small to draw definite conclusions, it was apparent that these procedures showed promise of being the best devised to date. However, since Duffner's (3) report in 1946, no evaluation of the Treatment Tables has been made.

3.15.2 Results of Treatment

(1) Although this report includes 935 cases of decompression sickness, only 888 cases were treated according to standard procedures set in the Treatment Tables. Therefore, the author will analyze only the results on the use of the Treatment Tables. The outcome of the other 47 cases was as follows: 43 were treated with non-standard procedures or deviations from the Treatment Tables and of this group 35 were completely relieved after one or more pressure treatments, 6 had permanent residuals, and 2 were fatal cases. The latter were very severe cases of decompression sickness that received inadequate initial pressure treatment. The remaining group of four cases received no pressure treatment. Of this group, three were completely relieved, and one died of massive decompression sickness.

(2) In the present analysis of 888 cases, the results are quite different from the Duffner (3) analysis. However, in the latter analysis all cases were among U. S. Navy divers and almost all of them were treated promptly. In the present analysis there are several categories of divers, as shown in Table 1, and several cases were not treated promptly.

(3) The results of the use of the treatment tables are shown in Table 18. An explanation of the headings on this table will be made for the purpose of clarification. The first column, labeled "Initial Treatment Table Used," refers to the Treatment Tables as proposed by Van Der Aue, et al (32) in 1945 and as used in the current U. S. Navy Diving Manual (2). The second column, labeled "Total Cases Treated," includes only cases that were treated exactly as outlined in the treatment tables with no deviations from standard procedures. The table is then divided into three parts. The first part, labeled Part A "Results of First Treatment," refers only to the results after the use of the initial treatment table. The second part, labeled Part B "Results after Further Treatment," shows the results after two or more treatment tables. It does not reflect on

TABLE 18
RESULTS OF TREATMENT

INITIAL TREATMENT TABLE USED	TOTAL CASES TREATED	PART A- RESULTS OF FIRST PRESSURE TREATMENT					PART B - RESULTS AFTER FURTHER PRESSURE TREATMENT				PART C - FINAL RESULTS			
		Re-lieved	Re-curred	Re-sidual	True Failures	% True Failures	Number Cases Re-treated	Re-lieved	Re-sidual	True Failures	Total Re-lieved	Total Re-sidual	Total True Failures	% Total True Fail-ures
1	291	269	22	0	16	5.5	22	22	0	0	291	0	0	-
1-A	92	79	12	1	6	6.5	13	11	2	0	90	2	0	-
2	215	195	17	3	13	6.0	17	17	0	0	212	3	0	-
2-A	73	66	6	1	3	4.1	6	6	0	0	72	1	0	-
3 (O_2)	69	64	5	0	5	7.2	5	2	3	3	66	3	3	4.3
3 (Air)	91	73	14	4	6	6.5	14	9	5	2	82	9	2	2.2
4 (Air)	33	18	4	11	5	15.1	5	2	3	1	20	13	4	12.1
4 (O_2)	12	5	0	7	3	25.0	1	0	1	0	5	7	3	25.0
4 (HeO_2)	12	4	2	6	3	25.0	3	1	2	1	5	7	3	25.0
TOTALS	888	773	82	33	60	6.7	86	70	16	7	843	45	15	1.7

the effectiveness of any treatment table since the second treatment table used was usually different and longer than the initial one. Also, some cases required more than two treatment tables. Details of the use of further pressure treatment is discussed in the section on "Analysis of 'Recurrences' and 'Residuals' that Received More Than One Treatment Table." It was for continuity purposes of the initial treatment table used, that the figures on the second and third part of Table 18 were kept in the same lineal order as in the first part. Part C of this table labeled "Final Results," shows the overall results of one or more treatment tables.

(4) The criteria used to classify the results of treatment will be defined. Cases classified as "relieved" refer to case completely relieved of all signs and symptoms. "Recurred" refers to cases which suffered a recurrence of signs or symptoms during or after the treatment table. "Residual" refers to cases that had definite residual manifestations upon completion of the treatment table. The criteria used on the latter group is definitely too strict. An attempt was made originally to classify as "residuals" only those cases which showed permanent residual manifestations 24 hours after completion of the treatment table. However, the follow-up data was not available in all cases; therefore, the classification refers to the immediate condition upon completion of the treatment table. Even if a case had shown a remarkable improvement during the treatment, as in cases of severe central nervous system manifestations that had a remarkable recovery, except for some localized neurological manifestations, they were considered "residuals." It must be pointed out that in many cases which terminated as a "residual," a follow-up letter usually indicated that after adequate physical therapy there had been significant improvement of neurologic manifestations, and the cases were considered as cured. In many cases of localized pain or "bends" the case was relieved of pain but upon completion of the treatment there were complaints of "soreness," "aches," or "discomfort" in the area where the pain was previously localized. These complaints were not considered as residual manifestations.

(5) The cases classified as "True Failures" refer to those "residuals" or "recurrences" in which there were no acceptable or valid reasons complicating the effectiveness of the proper use of the treatment tables. Failure in these cases was considered a true failure of the treatment tables. The acceptable or valid reasons that were responsible for failure of the treatment tables were, in order of frequency: (a) inadequate initial pressure treatment in accordance with standard procedures set in the treatment tables, either in recompression chambers or in the open water (67%); (b) delay in treatment of over 24 hours after onset of signs or symptoms (20%); (c) aggravation of the illness during an aircraft flight to the site of the recompression chamber (7%); and (d) alcoholic intoxication prior to, or following the dive (5%).

(6) The effectiveness of the treatment tables as a therapeutic measure is shown in Table 18. The percentage true failure of the initial use of the treatment tables was as follows:

Table 1............5.5%	Table 3 (O_2)....7.2%	Table 4 (Air)....15.1%
Table 1(A).........6.5%	Table 3 (Air)...6.5%	Table 4 (O_2).....25.0%
Table 2............6.0%		Table 4 (HeO_2)...25.0%
Table 2(A).........4.1%		

(7) In summary, Part A in Table 18 shows that of 888 cases treated, 773 were completely relieved with one treatment table. There was a total of 115 failures (82 recurrences and 33 residuals). Of the 115 failures, 55 were due to acceptable or valid reasons complicating the treatment, and 60 were due to true failure of the treatment tables. The total percentage true failure of the initial use of the treatment tables was 6.7%.

(8) Part B, Table 18 shows that of a total of 115 failures, only 86 cases were re-treated by one or more treatment tables, and usually by a different and longer treatment table. There were 70 cases relieved and 16 cases terminated as residuals. Of the latter, only 7 cases were due to true failure of the treatment tables.

(9) Part C, Table 18, shows the final results of the effectiveness of all the treatment tables and does not reflect the effectiveness of any specific treatment table, since in the cases that received further pressure treatment no mention is made of the treatment table used, or the number of treatment tables required to produce relief. Of 888 cases treated by one or more treatment tables, there were 843 cases relieved and 45 residuals. Of the latter, only 15 were due to true failure of the treatment tables. The total percentage true failure after using one or more treatment tables was 1.7%. In Duffner's (3) report, the total percentage true failure of one or more treatment tables was zero.

3.15.3 Interpretation of Results of Treatment

(1) The percentage true failure of the initial use of Treatment Tables 1, 1-A, 2, and 2-A is considered satisfactory. These are the tables used for simple cases of "bends" (pain only). It should be noted that all these cases recovered completely after further pressure treatment. During the construction of the third tube of the Lincoln Tunnel by the New York Port Authority during 1955-1956, Kooperstein and Schuman (35) reported 44 cases of mild decompression sickness. Thirty-one of these cases were treated by recompression and it was never found necessary to use any table other than Treatment Tables 1 or 1-A. Only 2 patients (6.4%) required hospitalization for further observation. There was no evidence of any permanent disability resulting from exposure to compressed air at the time.

(2) During the construction of the Tyne Tunnel in 1948-1950, Paton and Walder (10) reported 350 cases of decompression sickness. Only 3 cases had serious neurologic manifestations and 247 had "bends" or pain only. The procedure for treatment of "bends" cases was as follows: compress to working pressure plus 3 psi for 10-20 minutes, decompress rapidly to pressure laid down in decompression table and then slowly as laid down in tables for exposure of more than 4 hours to the working pressure (usually 90-100 minutes). For the serious cases a longer procedure was used also based on recompressing to the working pressure. In ordinary "bends" these methods proved effective, but 25% of the cases required more than one recompression, and 10% more than two recompression for relief of symptoms. Comparing these results with those in Table 18, it appears that the Treatment Tables for "pain

only" cases are more effective than the previously described treatment procedure. The only advantage of the latter procedure is the economy of time.

(3) The most recent series of cases of decompression sickness known to the author is the one during the construction of the Dartford Tunnel in 1957-1959. Campbell-Golding, et al. (36) reported 685 cases of decompression sickness. The cases were divided into two types: Type 1, or simple "bends" which accounted for 650 cases of the total, and Type 2, more serious and more complicated, of which there were 35 cases. The majority of the 650 cases classified as Type 1, or simple "bends" were treated by recompressing to 2-3 psi above the working pressure, and after being free of symptoms for 10 minutes were decompressed in the usual way as though for an exposure of more than 4 hours. If the patient was not free of symptoms after 1 hour at 3 psi above working pressure, a higher pressure was used. The pressure at which fast decompression ceased and the slow phase commenced, was, in every case, based on the highest pressure to which the man had been exposed in the previous 24 hours. The slow phase of the decompression was 9 minutes/psi. With this decompression time, however, 33% of the cases required two or more recompressions. For all cases after the first 50, the slow phase of decompression was therefore lengthened from 9 minutes/psi to 15 minutes/psi; even so 10% of the cases required further recompression. In all cases the patient was considered to be free from the pain of "bends" at the end of the treatment. The above results do not show any definite advantage, except for economy of time, over the Treatment Tables.

(4) A group of 56 of the 650 "bends" cases were treated by a different method. The pressure was raised only to the pressure required to make the patient symptom-free. After 10 minutes at the pressure, routine decompression was carried out. The average "minimum effective pressure" required was 8 psi below the working pressure. The results were very satisfactory, for only one case required a second recompression for complete recovery. Thus, they concluded that the best approach for treatment is to keep the therapeutic pressure as low as possible, so as to minimize any contribution which absorption of nitrogen during the recompression itself may make to recurrence of the lesion. The need for subsequent recompression was least when compression to the "minimum effective pressure" was used.

(5) The above series have been discussed to illustrate different approaches to the treatment of decompression sickness and compare them with the approach used in the Treatment Tables. Although there might be slight differences in the criteria used to classify the results, some apparent conclusions can be drawn. It appears that "bends" among tunnel workers are of a milder nature than "bends" among divers, and that relief of pain among the former occurs at lesser pressures than among the latter. One must remember that tunnel workers are not usually exposed to the high pressure under which divers routinely work. While the above treatment procedures were satisfactory for treating tunnel workers, the author doubts that they would be satisfactory for treating a group of divers as considered in the present series.

(6) Correlation of the depth of the dive with the depth of relief (Table 23) showed a slight positive correlation. That is, the shallower the depth of the dive the shallower the depth of relief. However, inspection of the data on Table 23 failed to show that the depth of exposure was usually the same as the depth of relief. Therefore, there is no justification to base treatment on the depth of exposure or depths greater than the exposure.

(7) It is the impression of the author that for mild cases of decompression sickness in tunnel workers, the treatment based on exposure to pressure or relief of symptoms is as effective as the one used in the Treatment Tables, i.e. using pressure greater than that needed for relief of symptoms.

3.15.4 Treatment of Serious Cases

(1) The results of treatment in serious cases (Table 18) showed that the percentage true failure of the initial use of Treatment Table 3 (O_2) was 7.2%, and Treatment Table 3 (Air) was 6.5%. These percentages are considered satisfactory. The percentage true failure for the initial use of Treatment Tables 4 was as follows: Table 4 (Air), 15.1%; Table 4 (O_2), 25.0%; Table 4 (HeO_2), 25.0%. Inspection of Table 18, Part C shows that there was little or no change in these percentages after further pressure treatment. One might be tempted to draw conclusions that results of Treatment Tables were poor. This is not so, since the cases that were treated initially with Treatment Tables 4 were severe cases of decompression sickness. Furthermore, some of the severe cases were not treated promptly.

(2) One cannot expect that the application of pressure will relieve all symptoms, since for cases in which tissue edema or hemorrhage has already occurred, increased pressure will have no effect on relieving either one. Increased pressure will reduce symptoms by diminishing the size of bubbles and increasing the oxygen saturation of tissues, but will have no direct effect on tissue edema or hemorrhage. Also, one must remember the criteria used in this series to classify cases as "cured."

(3) The author reviewed every case and in most of them there was a remarkable recovery after several days or weeks, especially those cases that received prompt physical therapy. Unfortunately, the data is not available on all cases to draw definite conclusions. Undoubtedly, the final outcome was much better than that shown in the figures on Table 18.

(4) In the Dartford Tunnel series, Campbell-Golding, et al. (36) reported 35 serious and complicated cases of decompression sickness. The last 16 cases in this group received a prolonged course of treatment which was as follows: the "minimum effective pressure" required to relieve signs and symptoms was maintained for one-half hour after all signs and symptoms had disappeared. The patient was then decompressed to 12 psi at the rate of 15 minutes/psi and "soaked" (i.e. maintained) at 12 psi for 4 hours. Decompression was then continued at the rate of 1 psi every one-half hour, "soaking" for 1½ hours at 8 psi, 1 hour at 4 psi, and 1 hour at 2 psi. This method took 15-20 hours. No additional recompressions were necessary after its use.

(5) Comparing this method with Treatment Table 3, one finds that time-wise they are similar since the latter takes about 19 hours. The 12 hour "soak" in Treatment Table 3 is probably comparable to the 4 hour "soak" at 12 psi (about 27 feet) used in the British method. It is interesting to note the difference between the U. S. Navy and the British method of decompression after the "soaking" period. In Treatment Table 3 and 4 after the 12 hour "soak" at 30 feet there are two more stops. One is at 20 feet and the other at 10 feet, each of 2 hours duration, with 1 minute between stops for a total decompression time of about 4 hours. In the British method the total time of decompression after the 4 hour "soak" at 12 psi (about 27 feet) is about 9½ hours. It takes 2 hours to go from the 12 psi (about 27 feet) "soak" or stop to the next stop at 8 psi (about 18 feet) which lasts 1½ hours. Then it takes 2 hours to go to the next stop at 4 psi (about 9 feet) which lasts 1 hour, then 1 hour to go to the next stop at 2 psi (about 4½ feet) which lasts for 1 hour, and finally it takes 1 hour to reach the surface.

(6) Although the number of cases treated by the British method was small, the results were very satisfactory. Whether this method would be successful in treating divers that are exposed to much greater pressures than the maximum working pressure at the Dartford Tunnel (28 psi or about 63 feet) is unknown to the author. Certainly, it will be interesting to investigate a modification in the shallower depths (less than 30 feet) of Treatment Tables 3 and 4. The modification should include more stops and more decompression time at the shallow depths. Another interesting investigation will be to shorten the 6 hour stops at 60 feet, 50 feet, and 40 feet in Treatment Table 4 and the time be used for decompression at shallower depths, as in the British method.

3.16 Analysis of "Recurrences" and "Residuals" That Received More Than One Treatment Table

3.16.1 The purpose of this section is to show in detail the treatment used after failure of the initial treatment table; also, to show the maximum number of times that a treatment table was required to produce complete relief. In order to avoid too much detail, no explanation is given as to the depth and time the failures occurred, or when further pressure treatment was started.

3.16.2 There were 22 cases in which failure of Treatment Table 1 occurred. All 22 cases recovered completely after a second treatment table. Re-treatment was as follows: Treatment Table 2, one case; Treatment Table 3 (O_2), two cases; Treatment Table 3 (Air), fourteen cases; Treatment Table 4 (Air), two cases; Treatment Table 4 (O_2), two cases; Treatment Table 4 (modified and extended), one case.

3.16.3 There were twelve cases in which failure of Treatment Table 1-A occurred. Eight cases were completely relieved after a second treatment. These cases were re-treated as follows: Treatment Table 2, one case; Treatment Table 3 (Air), four cases; Treatment Table 4 (Air), three cases. The other four cases had a different outcome and they were re-treated as follows: one case on Treatment Table 4 (Air); this case suffered a recurrence and was given a third treatment on a modified and extended Treatment Table 4 with complete recovery. Another case was re-treated on Treatment Table 4 (O_2); this case suffered a recurrence.

A third treatment was given on Treatment Table 4 (O_2) with complete recovery. Two cases were re-treated on Treatment Table 4 (HeO_2), and both suffered a residual after completion of the treatment.

3.16.4 After the initial use of Treatment Table 2 there were 17 failures. Sixteen were completely relieved after a second treatment table which was as follows: Treatment Table 2, 1 case; Treatment Table 3 (O_2), four cases; Treatment Table 3 (Air), eleven cases. The other case was re-treated on Treatment Table 3 (Air) and suffered a recurrence. This case was given a third treatment using Treatment Table 4 (O_2) and recovered completely.

3.16.5 There were six cases in which failure of Treatment Table 2-A occurred. All six were completely relieved with a second treatment table which was as follows: Treatment Table 3 (Air), three cases and Treatment Table 4 (Air), 3 cases.

3.16.6 There were five cases in which failure of Treatment Table 3 (O_2) occurred. Two were completely relieved after a second treatment table which was as follows: Treatment Table 2, one case and Treatment Table 3 (Air), one case. The other three received a second treatment on Table 4 (O_2) and terminated with a residual condition.

3.16.7 There were fourteen cases in which failure of Treatment Table 3 (Air) occurred. Eight were completely relieved after a second treatment which was as follows: Treatment Table 4 (Air), five cases; Treatment Table 4 (O_2), two cases; Treatment Table 4 (Modified), one case. The next five terminated in a residual condition after a second treatment which was as follows: Treatment Table 4 (Air), two cases; Treatment Table 4 (O_2), two cases; Treatment Table 3 (Air), one case. The other case received a second treatment on Table 4 (Air) which was followed by a recurrence. This case received a third treatment on Table 4 (Air), also followed by a recurrence. A fourth treatment was given on Table 4 (HeO_2) which terminated in a complete recovery.

3.16.8 There were five cases in which failure of Treatment Table 4 (Air) occurred. Two were completely relieved after a second treatment which was as follows: Treatment Table 2-A, one case; Treatment Table 3 (Air), 1 case. The other three received a second treatment and all terminated with a residual condition. The second treatment was as follows: Treatment Table 4 (Air), one case; Treatment Table 4 (O_2), one case; and Treatment Table 4 (HeO_2), one case.

3.16.9 There was one case in which failure of Treatment Table 4 (O_2) occurred. This case received a second treatment on Table 4 (HeO_2) and terminated with a residual condition.

3.16.10 There were three cases in which failure of Treatment Table 4 (HeO_2) occurred. One was relieved after a second treatment with Table 4 (HeO_2). The other two received a second treatment terminating with a residual condition. The second treatment was as follows: Treatment Table 4 (Air), one case; and Treatment Table 4 (HeO_2), one case.

3.16.11 In summary, of 888 cases treated initially with the Treatment Tables, 773 were completely relieved with the first treatment table. There were 115 failures (82 recurrences and 33 residuals). Only 78 of these failures received a second treatment table with the following results: 64 relieved, 17 residuals, and 4 recurrences. A third treatment table was given to the four recurrences, terminating in complete recovery for three cases, and a recurrence for one case. The case that recurred was finally relieved after receiving a fourth treatment table.

3.17 Relationship between Delay of Treatment After the Time of Onset of Signs and Symptoms and Results of Treatment - (Table 19)

3.17.1 Since other investigators have indicated that varying the time between treatment and the initial onset of symptom can affect the final outcome of treatment, this relationship was analyzed. The results are presented in Table 19.

TABLE 19
RELATIONSHIP BETWEEN DELAY OF TREATMENT AFTER THE TIME OF ONSET OF SIGNS AND SYMPTOMS AND RESULTS OF TREATMENT

Delay Sx - Rx	Total Cases	PART-A RESULTS OF FIRST TREATMENT				PART-B RESULTS AFTER FURTHER TREATMENT		
		Relieved	Recurred	Residual	% Relieved	Total Relieved	Total Residual	% Relieved
Under 15 min.	175	160	14	1	91.4	171	4	97.7
15 - 30 min.	89	85	4	0	95.5	88	1	98.8
31 - 60 min.	116	104	11	1	89.6	114	3	98.2
61 - 120 min.	136	122	12	2	89.7	134	2	98.2
3 - 6 hours	172	147	18	7	85.5	164	8	95.9
7 - 12	91	70	14	7	76.9	79	12	86.8
12 - 24	70	60	4	6	85.7	64	6	91.4
25 - 36	21	16	4	1	76.2	19	2	90.4
37 - 48	6	2	1	3	33.2	3	3	50.0
49 - 96	7	4	0	3	57.2	4	3	57.1
97 - 144	2	0	0	2	0.0	0	2	0.0
Unknown	3	3	0	0	100.0	3	0	100.0
TOTAL	888							

$X^2 = 19.0$, df = 3, $p < .01$, N for $X^2 = 885$

3.17.2 Keays (21) and his associates were convinced that the benefits resulting from recompression were definitely dependent upon prompt treatment, and have presented information which gives evidence for this belief. Keay's cases followed exposures of 42 psi maximum. During the years 1935-1939 at the Experimental Diving Unit (31), in 2295 dives where the pressures varied from 44 to 200 psi, there occurred 94 cases of decompression sickness. Of these cases, 91 were treated within 2 hours after the appearance of the first symptom, 97.7% were relieved by one or more recompressions, partial relief was obtained by 1.1% and no relief in 1.1% of the cases.

3.17.3 Since there were only three cases receiving treatment two to four hours after onset, no comparative evidence of early treatment benefit was presented. The high incidence of cures and the absence of persistent lesions from nervous tissue injury, however, reflects favorably on early treatment. The most noteworthy fact in the EDU series of cases was the small number of cases presenting nervous system symptoms in which only partial relief was obtained. Therefore, the contention of Langlois (37) is here borne out in that early recompression may do much to avoid persistent symptoms due to irrepairable damage to some nervous tissues.

3.17.4 Paton and Walder (10) found that with ordinary cases of "bends" the later the recompression after onset of symptoms the more effective (in the sense of not requiring to be repeated) it became. They give as an explanation for this that an attack of "bends" is in any case self-limiting, and that even without treatment it would usually pass off in 24-28 hours. However, they realized that with serious cases of decompression sickness, especially those involving the spinal cord, the sooner the recompression takes place, the less damage will be, and that prompt termination of any attack of "bends" will avoid late sequels of "bends."

3.17.5 To determine if the delay in treatment after the initial onset of symptoms bore some relationship to the outcome of the treatment, the data appearing in Table 19 were submitted to a chi square test. The 41 cases where the delay in treatment was unknown were, of course, dropped from the analysis, leaving a remainder of 847 cases.

3.17.6 The test was accomplished by combining the 847 cases into four groups according to the delay in treatment after the onset of symptoms, such as under 15 minutes, 15-30 minutes, etc. The four groups were then compared statistically to determine if they differed significantly in the number of cases who responded well to the first compression treatment. The criterion of a good response to treatment was based on the number of cases who were relieved. Those cases which had a recurrence or a residual were considered not relieved.

3.17.7 A chi square value of 19.00 ($p<.01$) was obtained from this analysis, demonstrating that the four groups did differ in their response to treatment. Therefore, it can be concluded that a delay in treatment after the onset of symptoms is related to the outcome or treatment. The chi square test does not indicate the direction of the difference. This was determined by inspection, which indicates that, in general, the longer the delay in treatment, the poorer the outcome of the case. The results of the under 15 minutes group are incongruent with the general finding; this group should have responded better than the others. The specious incongruity might be explained by the fact that the very severe cases usually exhibit symptoms soon after surfacing and immediate treatment is typically attempted. The poorer outcome of this group having a delay of less than 15 minutes is probably, then, due to the inclusion of the more severe cases.

3.17.8 The author does not wish to imply that because of the evident advantage of early treatment, cases which have existed for some time should not be recompressed. Rather, it is to be emphasized that all cases should be given a recompression trial no matter what the elapsed time since the onset. Recovery was noted in cases in which the delay was as much as four days. There are recorded cases of recovery by recompression performed several days after the onset of symptoms (38).

3.18 <u>Relationship between Time of Onset of Signs and Symptoms and Results of Treatment - (Table 20)</u>

3.18.1 To ascertain the relationship between time of onset of symptoms and the outcome of treatment, a chi square analysis of the data (Table 20, Part A) under conditions similar to the previously discussed section was performed. In this instance, four groups were formed according to the time when the initial onset of symptoms was noted after the dive, and then the number of cases which were completely relieved for the four groups were compared. A significant chi square value of 8.75 ($p<.05$) was obtained indicating that the outcome of treatment is related to the time of onset of symptoms.

TABLE 20
RELATIONSHIP BETWEEN TIME OF ONSET OF SIGNS AND SYMPTOMS AND RESULTS OF TREATMENT

TIME OF ONSET	TOTAL CASES	PART-A RESULT OF FIRST TREATMENT				PART-B RESULTS AFTER FURTHER TREATMENT		
		Relieved	Recurred	Residual	% Relieved	Total Relieved	Total Residual	Total Relieved
During dec.	70	58	6	6	82.9	61	9	87.2
First hour	408	340	44	24	83.3	376	32	92.1
1 - 2 hours	108	100	8	0	93.6	108	0	100.0
3 - 6	175	160	14	1	91.5	174	1	99.4
7 - 12	61	54	6	1	88.5	59	2	96.7
13 - 24	22	21	0	1	95.4	21	1	95.4
25 - 36	3	3	0	0	100.0	3	0	100.0
Unknown	41	37	4	0	90.2	40	1	97.6
TOTAL	888							

$X^2 = 8.76$, df = 3, $p<.05$, N for $X^2 = 847$

3.18.2 The direction of the difference for delays in symptom onset seems to be opposite to that found for delay of treatment. A delay in the appearance of symptoms resulted in a better outcome. The explanation is probably that symptoms appear earlier in more severe cases, and therefore, the poor prognosis of early symptom manifestation can be attributed to severity. If this explanation is valid, it would further substantiate the explanation given for the less satisfactory outcome of treatment for cases treated in less than 15 minutes as discussed in the last section. Although prompt treatment is generally beneficial, persons exhibiting very early symptoms are usually the more severe cases. Therefore, expeditious treatment does not appear to be as effective for early symptoms as it does in those cases which manifest symptoms later. The strength of the relationship between the delay of treatment and the result of treatment is probably weakened by the factor of severity.

3.18.3 In the analysis of Table 19 and 20, an index of severity, indicating whether a case was simple or serious, would have allowed for more conclusive statements. Unfortunately, this information was not available. Paton and Walder (10) analyzed simple cases of "bends" and the ease with which it could be relieved. They found a significant correlation between ease of relief of the "bends" and the time of onset, the "bends" being more easily relieved the later they occurred.

3.19 <u>Relationship between Delay of Treatment and Depth of Relief - (Table 21)</u>

3.19.1 To indicate how closely the depth of relief is influenced by the delay of treatment after the onset of symptoms, a coefficient of contingency was determined for Table 21. Cases that were relieved at 165 feet were not included because relief at 165 feet will vary from time of arrival at the depth up to 2 hours. Therefore, the variable of time, in addition to depth, has some bearing on the occurrence of relief at the depth of 165 feet. The relationship between the delay of treatment and depth of relief was slightly positive ($C = .25$, $N = 246$); that is, the shorter delays tend to require shallower depths for relief.

3.19.2 Paton and Walder (10) found that the pressure at which relief from a simple "bends" was obtained during recompression bore no relation to the delay before recompression.

3.20 <u>Relationship between Time of Onset of Signs and Symptoms and Depth of Relief - (Table 22)</u>

3.20.1 Depth of relief was only slightly positively correlated with the time of onset of symptoms ($C = .15$, $N = 615$). A shorter time before onset of symptoms generally requires a shallower depth of relief, but exceptions are frequent.

3.20.2 These results at first appear incongruent with the results obtained from Table 20 where these cases developing symptoms early had a poorer outcome. However, inspection of the data indicated similar results in both tables. Within the group reporting symptoms during recompression, nearly half were taken to deeper depths. This tends to confirm the previous discussion of Table 20, that an immediate onset is more detrimental to treatment due to serious cases. The rest of the table is in better agreement with the obtained C value. That is, a longer period before onset of symptoms requires a deeper depth of relief.

TABLE 21
RELATIONSHIP BETWEEN DELAY OF TREATMENT AND DEPTH OF RELIEF

Delay Sx - Rx	NUMBER OF CASES IN WHICH DEPTH OF COMPLETE RELIEF WAS: (FEET)									Total
	0-33	34-66	67-99	100-132	133-164	165	Partial Relief	No Relief 165	Unk	
Under 15 min.	58	62	17	11	0	23	4	0	0	175
15 - 30	31	31	8	6	1	12	0	0	0	89
31 - 60	22	46	11	6	5	23	3	0	0	116
60 - 120	24	54	14	16	5	20	2	1	0	136
3 - 6 hours	30	54	7	25	7	32	13	3	1	172
7 - 12	6	22	7	7	3	29	12	4	1	91
13 - 24	4	22	4	3	3	22	8	3	1	70
25 - 36	2	3	0	2	0	8	4	1	1	21
37 - 48	1	0	0	2	0	2	0	1	0	6
49 - 96	0	2	1	0	1	0	1	2	0	7
97 - 144	0	0	0	0	0	0	1	1	0	2
Unknown	1	0	0	0	0	1	0	0	1	3
TOTAL	179	296	69	78	25	172	48	16	5	888

C = .25

3.20.3 Paton and Walder (10) found that the pressure at which relief from simple "bends" was obtained during recompression bore no relation to time of onset of signs and symptoms.

TABLE 22
RELATIONSHIP BETWEEN TIME OF ONSET OF SIGNS AND SYMPTOMS AND DEPTH OF RELIEF

TIME OF ONSET	NUMBER OF CASES IN WHICH DEPTH OF COMPLETE RELIEF WAS: (FEET)									Total
	0-33	34-66	67-99	100-132	133-164	165	Partial Relief 165	No Relief 165	Unknown	
During dec.	11	21	6	9	0	12	9	2	0	70
First hour	93	122	29	28	9	89	27	9	2	408
1 - 2	30	40	7	9	4	15	1	1	1	108
3 - 6	27	66	19	21	7	31	3	1	0	175
7 - 12	8	22	4	3	3	14	3	3	1	61
13 - 24	4	6	2	3	1	4	2	0	0	22
25 - 36	0	1	0	0	0	1	1	0	0	3
Unknown	6	18	2	5	1	6	2	0	1	41
TOTAL	179	296	69	78	25	172	48	16	5	888

C = .15

3.21 Relationship between Depth of Dive and Depth of Relief - (Table 23)

Depth of relief was also positively correlated with the depth of the dive (C = .15, N = 643). That is, the shallower the depth of the dive the shallower the depth of relief. The correlation, however, was again very low. The C values obtained from Tables 21, 22, and 23 are so low that the relationships are negligible. However, the relationships may be stronger than indicated. The severity of cases is again, an uncontrolled factor. Some control of severity, and if it were possible, the inclusion of cases relieved at 165 feet might have strengthened the relationships.

TABLE 23
RELATIONSHIP BETWEEN DEPTH OF DIVE AND DEPTH OF RELIEF

DEPTH OF THE DIVE	NUMBER OF CASES IN WHICH DEPTH OF COMPLETE RELIEF WAS: (FEET)									Total
	0-33	34-66	67-99	100-132	133-164	165	Partial Relief 165	No Relief 165	Unknown	
0 - 33	1	2	-	-	-	-	-	-	-	3
34 - 99	43	82	19	19	6	43	7	3	2	224
100 - 165	77	129	30	37	10	71	25	11	-	390
166 - 231	38	45	8	12	4	28	10	1	3	149
232 - 297	12	21	3	2	3	9	4	-	-	54
298 - 495	8	15	8	7	2	19	2	1	-	62
Unk-other	-	2	1	1	-	2	-	-	-	6
TOTAL	179	296	69	78	25	172	48	16	5	888

C = .15

4. CONCLUSIONS

4.1 Status of Cases

The data showed that 2 out of every 10 divers with decompression sickness treated by the U. S. Navy were civilians.

4.2 Cases Occurring After Proper Decompression

4.2.1 A small incidence of decompression sickness occurred following dives in which adequate decompression was used or no decompression was required in accordance with the U. S. Navy Decompression Tables.

4.2.2 Healthy subjects acting as tenders during treatment tables occasionally developed decompression sickness. This was more common while tending during Treatment Table 4.

4.3 Manifestation of Decompression Sickness

Decompression sickness is a disease of protean manifestations usually affecting one or more of the following organ-systems, in order of frequency: localized pain in skeletal-muscular system, central nervous system, peripheral nervous system, skin, and respiratory system. Localized pain is the most frequent manifestation among divers, as well as tunnel workers. In divers, the location of pain was more frequent in the upper extremities than in the lower extremities, the opposite of the findings from studies of tunnel workers. The incidence of central nervous system involvement was higher in divers than tunnel workers.

4.4 Time of Onset of Symptoms

The time of onset of symptoms in decompression sickness varies widely; however, the greatest number of cases had a relatively rapid onset. It was very rare for a case to develop 24 hours after completion of a dive.

4.5 Efficacy of Treatment Tables

The results of treatment by utilizing the Treatment Tables were satisfactory. The treatment of mild cases of decompression sickness in tunnel workers by exposing the patient to the pressure of relief of symptoms was as effective as the one used in the Treatment Tables, where a pressure greater than that needed for relief of symptoms is used. The latter approach was the most effective for the treatment of serious cases.

4.6 Relationship Between Delay in Treatment and Outcome of Treatment

A delay in giving pressure treatment for decompression sickness after the onset of symptoms is significantly related ($X^2 = 19.00$ $p<.01$) to the outcome of treatment. Generally, the sooner the recompression begins the better the outcome of the treatment. Prognosis is poor when the delay of treatment is over 36 hours after the appearance of symptoms, but recovery has been noted when the delay was as much as four days.

4.7 Relationship Between Time of Onset of Symptoms and Outcome of Treatment

The results of pressure treatment for decompression sickness were significantly related ($X^2 = 8.76$, $p<.05$) to the time of onset of symptoms. Generally, cases having a shorter time of onset respond less satisfactorily than those exhibiting symptoms after a relatively longer time.

4.8 Relationship Between Delay of Treatment and Depth of Relief

The relationship between the delay of recompression after the onset of symptoms of decompression sickness and the depth of relief was slightly positive ($C = .25$). That is, the shorter delays require a shallower depth of recompression for relief more often than deeper depths.

4.9 Relationship Between onset of Symptoms and Depth of Relief

The depth of relief during pressure treatment of decompression sickness was slightly and positively correlated with the time of onset of symptoms (C = .15) That is, a shorter time before onset of symptoms generally requires a shallower depth of relief. The relationship, however, is essentially negligible.

4.10 Relationship Between Depth of Dive and Depth of Relief

The depth of relief was also positively correlated with the depth of the dive to a minor degree (C = .15). That is, the shallower the depth of the dive, the shallower the depth of relief.

5. RECOMMENDATIONS

5.1 Investigation of Incidence of Decompression Sickness in Tenders

The reason for tenders acquiring decompression sickness during or after a treatment table should be investigated.

5.2 Safety Period Before Release of Divers

It is recommended that after completion of a dive, 24 hours is the safest period to wait for the appearance of symptoms before a divers leaves an area where a recompression chamber is available.

5.3 Attempts to Treat Delayed Cases

All cases of decompression sickness should be given a recompression trial no matter what the elapsed time since the onset. Some cases were relieved when the delay of pressure treatment was as much as four days.

5.4 Investigation of Modifications of Treatment Tables

It will be interesting to investigate a modification in the shallower depths (less than 30 feet) of the U. S. Navy Treatment Tables 3 and 4. The modification should include more stops and more decompression time at these shallow depths. Another interesting investigation in Treatment Table 4 will be to shorten the 6 hour stops at 60 feet, 50 feet and 40 feet and the time be used for decompression at shallower depths as used in the British method by Campbell-Golding, et al (36).

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APPENDIX A

DIVING CASUALTY DATA CARD

DATE OF ACCIDENT (YEAR, MONTH) — NAME CODE

7 4 2 1 | 7 4 2 1 | 7 4 2 1 | 2 1 | 7 4 2 1 | 7 4 2 1

1. NAME RANK RATE SERVICE CORPS ID NUMBER
2. REPORTING ACTIVITY
3. DATE OF ACCIDENT
4. DATE OF REPORT
5. MEDICAL DEPARTMENT REPRESENTATIVE
6. DIVERS WEIGHT
7. DIVERS HEIGHT
8. DESCRIPTION OF DIVE

	DIVE DEPTH	BOTTOM TIME	SURFACE INTERVAL
FIRST			
SECOND			
THIRD			
FOURTH			

9. LOCATION OF REPORT USED AS SOURCE

*NOTES ON REVERSE OF CARD WITH REFERENCE TO SECTION AND ITEM NUMBER. ENTRIES MARKED WITH AN ASTERISK REQUIRE A NOTE

IN REPETITIVE DIVES, PUNCH EQUIVALENT SINGLE DIVE TIME (E. S. D. T.) OF LAST DIVE IN SECTION 23.

40. SIGNS OR SYMPTOMS DURING ILLNESS. (INNER PUNCH INDICATES FIRST SYMPTOM)

41. LOCATION (IF APPLICABLE): HEAD 1, NECK 2, BACK 3, HAND 4, WRIST 5, FOREARM 6, ELBOW 7, SHOULDER 8, FOOT 9, LEG 10, THIGH 11, KNEE 12, HIP 13, GROIN 14, ABDOMEN 15, CHEST 16, FACE 17, EAR 18, OTHER 19, 20

Signs or symptoms: LOCALIZED PAIN* 1; MUSCULAR WEAKNESS * 2; NUMBNESS, PARESTHESIA * 3; RASH 4; UNDUE FATIGUE 5; PARALYSIS; DYSPNEA (CHOKES); TWITCHING; CONVULSION; UNCONSCIOUSNESS; NAUSEA OR VOMITING; DIZZINESS OR VERTIGO 12; VISUAL DISTURBANCES * 13; AUDITORY DISTURBANCES * 14; HEADACHE 15; BLEEDING * 16; HEMOPTYSIS 17; AGITATION 18; INCOORDINATION 19; EQUILIBRIUM DISTURBANCES 20; PERSONALITY CHANGE 21; CRANIAL NERVE (OTHER THAN II-VIII)* 22; EMPHYSEMA * 23; PNEUMOTHORAX 24; URINARY SYMPTOMS * 25

39. RECURRENCES 1 2 3 4 5 OTHER

10.

11. CLASS: OTHER; FOREIGN NATIONAL; CIVILIAN, GOVT OR COMM; CIVILIAN SPORT; OTHER U S MILITARY; NAVY

12. AGE: UNDER 20 YEARS; 21 TO 25 YEARS; 26 TO 30 YEARS; 31 TO 35 YEARS; 36 TO 40 YEARS; OVER 40 YEARS

13. BUILD: OBESE; HEAVY; MEDIUM; SLENDER

14. QUALIFICATIONS: STUDENT; UWS; EOD; UDT; DEEP SEA OR SALVAGE

15. PURPOSE OF DIVE: OTHER; WORK; REQUALIFICATION; EXPERIMENTAL; SELECTION; TRAINING (OF DIVER)

16. TYPE OF DIVE: OTHER; SUB. ESCAPE TANK; SEA OR HARBOR; CHAMBER; DRY; WET

17. TEACHING CASE *; 18. LAB. *; 19. VITAL SIGNS; 20. HOT-REL. HOSPIL. *; 21. REPET. DIVE

22. DEPTH (GAGE): 0-33 FEET 1; 34-99 FEET 2; 100-165 3; 166-231 4; 232-297 5; 298-495 6; 496-660 7; 661 FT. PLUS 8; MULTILEVEL 9; UNKNOWN OR OTH. 10

23. BOTTOM TIME: LESS THAN 15 1; 15-30 MIN. 2; 30-45 MIN 3; 45-60 MIN 4; 60-90 MIN 5; 90-120 MIN. 6; GREATER THAN 120 7; OTHER 8

24. TYPE OF EQUIPMENT: FREE ESCAPE OR ASCENT 1; ESCAPE DEVICE * 2; LIGHT WEIGHT, SURFACE SUPPLY 3; DEEP SEA AIR 4; DEEP SEA, HELIUM 5; SCUBA, OPEN 6; SCUBA, CLOSED 7; SCUBA, SEMICLOSED 8; RECOMPRESSION CHAMBER 9; EXPERIMENTAL EQUIPMENT * 10; NO EQUIPMENT * 11; OTHER * 12

25. TYPE OF WORK: NONE 1; MILD 2; MODERATE 3; HEAVY 4

26. BREATHING MEDIUM: HELIUM - OXYGEN (SPECIFY %) * 1; AIR 2; OXYGEN 3; OTHER MIXTURE * 4; EXPERIMENTAL * 5; OTHER * 6

27. SOURCE OF MEDIUM: GASOLINE COMPRESSOR 1; HAND PUMP 2; AIR BANKS 3; HELIUM - OXYGEN BANKS 4; COMMERCIAL 5; OTHER * 6

28. DECOMPRESSION SCHEDULE: AIR TABLES 1; HELIUM - OXYGEN TABLES 2; EXCEPTIONAL EXPOSURE (SATURATION) 3; SURFACE DECOMPRESSION SCHEDULE 4; NO DECOMPRESSION STOPS REQUIRED 5; O2 IN DECOMPRESSION 6; LESS THAN PROPER SCHEDULE 7; EXPERIMENTAL * 8; DIVING MANUALS 1943, 1952 9; "REVISED TABLES" 10; 11; 12

— PUNCH HOLES THESE SECTIONS BOTTOM OF CARD —

29. CONTRIBUTING FACTORS (NON MED.): EXTREME COLD 1; EXTREME HEAT 2; ROUGH SEA OR UNUSUAL CURRENTS 3; FAULTY EQUIPMENT 4; COMMUNICATION FAILURE 5; 6; DEPARTURE FROM ACCEPTED PROCEDURES * 7; OTHER * 8

30. TIME OF ONSET OF SYMPTOMS: ON BOTTOM 1; DURING DECOMPRESSION OR ASCENT 2; FIRST HOUR 3; SECOND HOUR 4; THIRD TO SIXTH HOUR 5; SEVENTH TO TWELFTH HOUR 6; 12 TO 24 HOURS 7; MORE THAN 24 HOURS 8

31. DELAY SX-RX (WITH PRESSURE): UNDER 15 MIN. 1; 15 TO 30 MIN. 2; 30 MIN. TO 1 HR. 3; 1 - 2 HOURS 4; 2 - 6 HOURS 5; 6 - 12 HOURS 6; 12 - 24 HOURS 7; 24 PLUS HOURS 8

32. RESULT: RELIEVED; FATAL *; RESIDUAL 1ST 24 HRS; RESIDUAL OVER 24 HRS.; PERMANENT RESIDUAL; REOCCURENCE; HOSPITAL *; OTHER *

33. NO OF PREV ACCIDENTS: 0 1 2 3 4 MORE

34. DEPTH OF RELIEF — FULL RELIEF: 0-33 FEET; 34-66 FEET; 67-99 FEET; 100-132 FEET; 133-164 FEET; 165 OR OVER — FIRST SIGN OR SYMPTOM: 0-33 FEET; 34-66 FEET; 67-99 FEET; 100-132 FEET; 133-164 FEET; 165 FT. OR OVER

35. TYPE OF ACCIDENT: DECOMPRESSION SICKNESS; OVER PRESS. OF LUNGS; SYNCOPE *; NITROGEN NARCOSIS; CO_2; O_2; NON PRESSURE TRAUMA; DROWNING; OTHERS *

36. TYPE OF TREATMENT *: I-A; II; II-A; III (O_2); III AIR; IV (AIR TIME AT 165 FT) *; IV (HeO_2); OTHER PRESSURE TREAT. *; OTHER NON-PRESSURE TREAT. *; TREATMENT IN WATER *

37. D.S. ORGAN SYSTEM INV: PAIN ONLY; CNS; PERIPHERAL N S.; SKIN; RESPIRATORY; OTHER

38. OVER PRESS. OF LUNGS: AIR EMBOLISM; MEDIASTINAL EMPHYSEMA; SUB CUTANEOUS EMPHYSEMA; PNEUMOTHORAX; SYNCOPE *; OTHER

29. 30. 31.

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